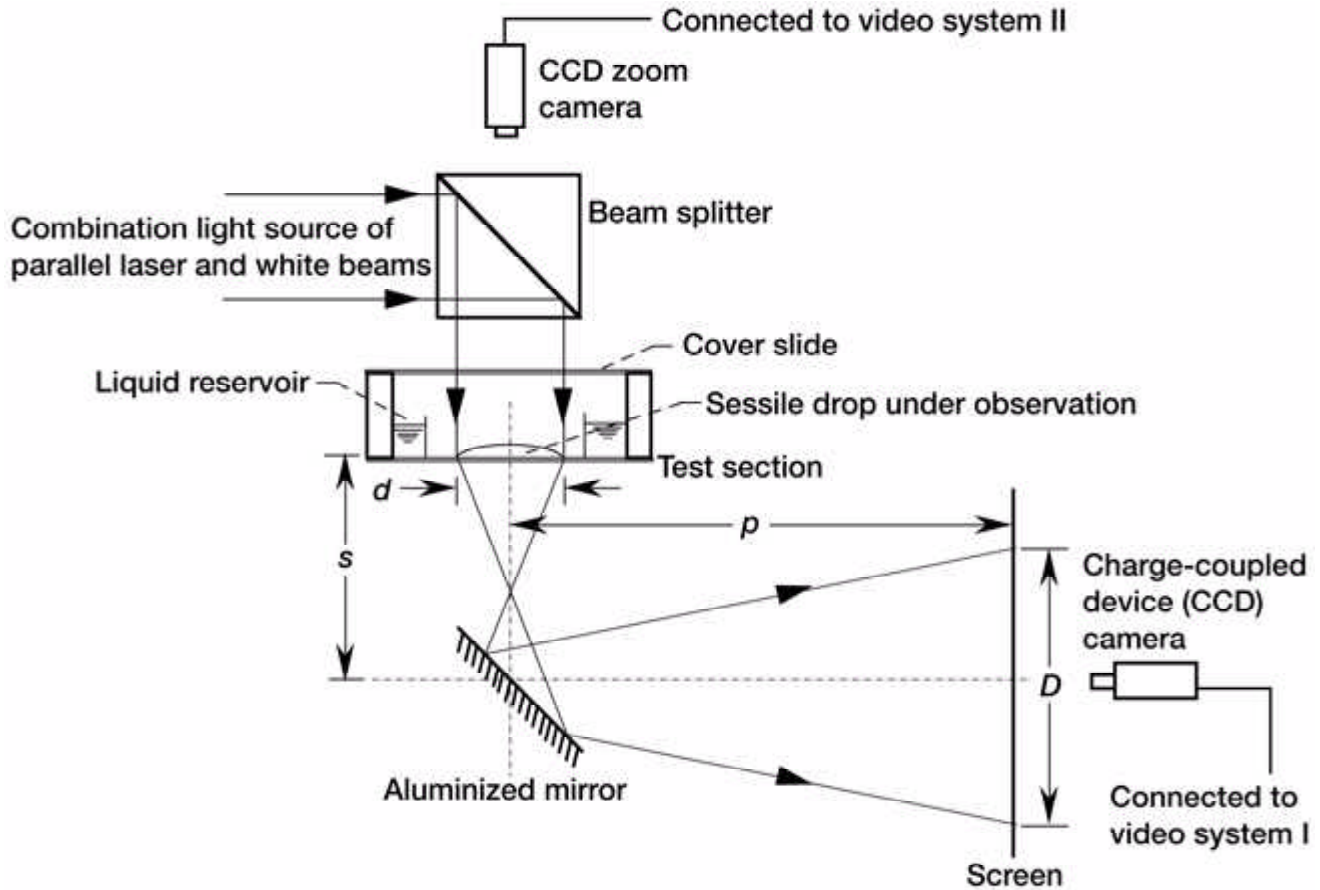


New Method Developed to Measure Contact Angles of a Sessile Drop

The spreading of an evaporating liquid on a solid surface occurs in many practical processes and is of importance in a number of practical situations such as painting, textile dyeing, coating, gluing, and thermal engineering. Typical processes involving heat transfer where the contact angle plays an important role are film cooling, boiling, and the heat transfer through heat pipes. The biological phenomenon of cell spreading also is analogous to a drop spreading (ref. 1). In the study of spreading, the dynamic contact angle describes the interfacial properties on solid substrates and, therefore, has been studied by physicists and fluid mechanics investigators. The dynamic contact angle of a spreading nonvolatile liquid drop provides a simple tool in the study of the free-boundary problem, but the study of the spreading of a volatile liquid drop is of more practical interest because the evaporation of common liquids is inevitable in practical processes.

The most common method to measure the contact angle, the contact radius, and the height of a sessile drop on a solid surface is to view the drop from its edge through an optical microscope. However, this method gives only local information in the view direction. Zhang and Yang (ref. 2) developed a laser shadowgraphy method to investigate the evaporation of sessile drop on a glass plate. As described here, Zhang and Chao (refs. 3 and 4) improved the method and suggested a new optical arrangement to measure the dynamic contact angle and the instant evaporation rate of a sessile drop with much higher accuracy (less than 1 percent). With this method, any fluid motion in the evaporating drop can be visualized through shadowgraphy without using a tracer, which often affects the field under investigation.

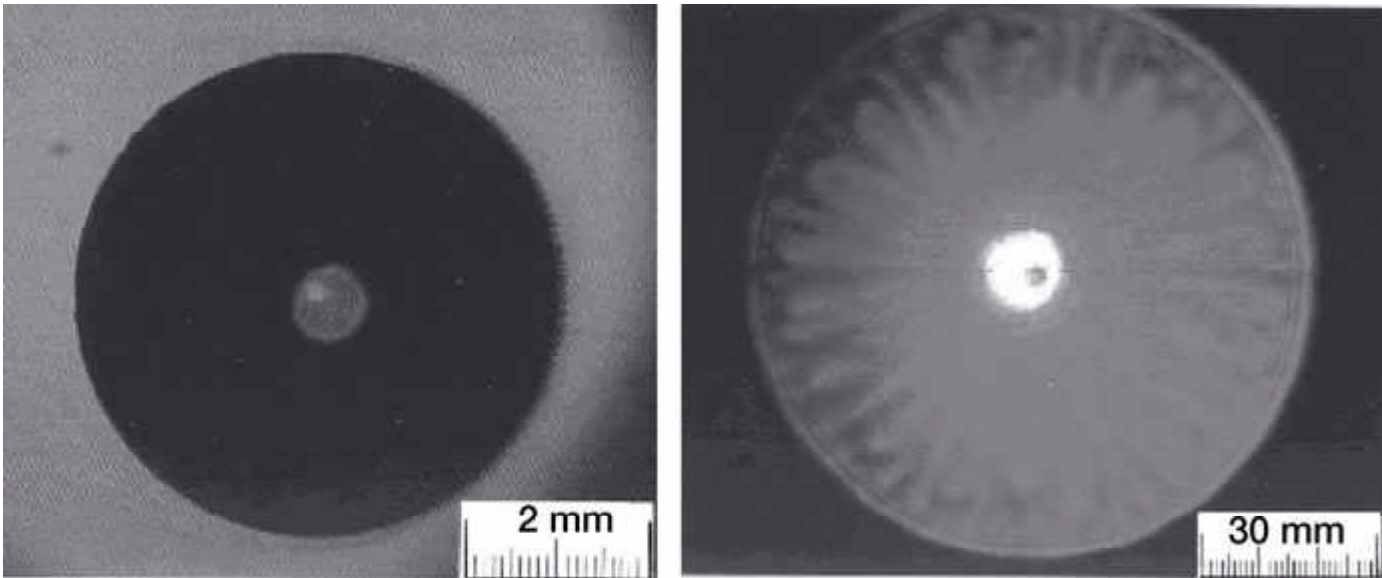


Apparatus for measuring spreading and contact angle.

Long description Diagram of apparatus showing connections from video system II, to charge-coupled device (CCD) zoom camera, to beam splitter, to combination light source of parallel laser and white beams, through cover slide, to liquid reservoir, to sessile drop under observation, to the test section (with height s , width d , and length p), through an aluminized mirror, to a screen of height D , to a CCD camera connected to video system I.

This illustration depicts an apparatus that simultaneously and synchronously records magnified ordinary top-view video images and laser-shadowgraph video images of a sessile drop. The shadowgraphs contain flow patterns indicative of thermocapillary convection (if any) within the drop. One can determine the time-dependent parameters of the drop--such as the contact diameter, contact angle, and evaporation rate--by measuring the apparent diameters in the timed sequence of images. The apparatus combines a collimated white-light beam and a collimated laser beam. A charge-coupled-device (CCD) camera connected to video system I acquires the shadowgraph images, while a CCD zoom camera connected to video system II acquires the ordinary top-view images. Assuming that the drop takes the shape of a sphere cap, it can be considered as a plano-convex lens. The time-dependent contact angle is given by $\theta(t) = \arcsin\{[d(t) + D(t)] / [2(n - 1)(s + p)]\}$, where n is the index of refraction of the liquid in the drop, s and p are the constant dimensions indicated in the illustration on the previous page, d is the time-dependent (t) diameter of the drop measured in the ordinary image acquired by video

system II, and D is the time-dependent diameter of the shadowgraph acquired by video system I (as shown in the following images). This technology is currently under development at NASA Glenn Research Center's Fluids Physics Branch of the Microgravity Science Division.



Sessile drop. Left: Typical top-view image. Right: Laser shadowgraphic image.

References

1. Greenspan, H.P.: On the Motion of a Small Viscous Droplet That Wets a Surface. J. Fluid Mech., vol. 84, part 1, 1978, pp. 125-143.
2. Zhang, Nengli; and Yang, Wen-Jei: Natural Convection in Evaporating Minute Drops. J. Heat Transfer Trans. ASME, vol. 104, no. 4, 1982, pp. 656-662.
3. Zhang, Nengli; and Chao, David F.: A New Approach to Measure Contact Angle and Evaporation Rate With Flow Visualization in a Sessile Drop. NASA/TM-1999-209636, 1999.
4. Chao, David F.; and Zhang, Nengli: Effects of Evaporation and Thermocapillary Convection on Volatile Liquid Droplets. J. Thermophysics Heat Trans., vol. 15, no. 4, 2001, pp. 416-420.

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